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INVESTIGATION OF FUSELAGE ACOUSTIC TREATMENT FOR A TWIN-ENGINE TURBOPROP AIRCRAFT IN FLIGHT AND LABORATORY TESTS

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INTRODUCTION

Propeller noise transmitted through the fuselage sidewall is an important source of interior noise in twin-engine turpoprop aircraft. One method of reducing such noise is the use of acoustical materials attached to the inner side of the sidewall. These treatments should have maximum acoustic insulation but minimum weight to avoid aircraft performance penalties.

The development of treatment configurations is not a straightforward matter, but usually requires a combination of design and testing of several configurations. If this development could be carried out using laboratory tests and theoretical predictions, there would be potential for better acoustic performance of the treatment at lower cost compared to aircraft flight testing. However, in order to use the laboratory approach it must be shown that the performance of the acoustic treatment in flight can be predicted based on the laboratory test results.

A substantial amount of research has been done on sidewall acoustic treatment for aircraft. This research has included theoretical and laboratory experimental studies; however, no results appear to be available in the literature on the behavior of acoustic treatment in flight or on flight measurement techniques for investigating acoustic treatment effects on cabin noise. The flight tests described here were undertaken, therefore, as an initial attempt to investigate sidewall acoustic treatment, using an aircraft for which parallel theoretical and experimental laboratory studies were underway.

In the study reported here, the ability to predict treatment performance is examined by comparing acoustic results for three treatment configurations measured in flight and measured in laboratory transmission loss tests. The aircraft used is a modern, high-performance, twin-engine turboprop aircraft with a pressurized cabin, and was operated at a representative cruise condition for the acoustic

tests. The treatment configurations are typical examples of designs that might be considered to provide high transmission loss for propeller noise. In order to focus attention on the treatment, results are presented in terms of insertion loss, defined as the reduction of cabin noise level that occurs when a treatment is added to the sidewall. Laboratory studies used a specially designed panel structure and acoustic treatments (fiberglass, damping tape, and mass-loaded vinyl septa) that closely represent the aircraft configurations.

ACOUSTIC TREATMENT PERFORMANCE IN FLIGHT

Aircraft and Test Conditions

The aircraft, illustrated in figure 1, has a maximum take-off weight of about 11,200 lbs, a standard cabin layout for a pilot and seven passengers and is powered by two turbo shaft engines which are flat rated to a maximum of about 800 HP. The synchrophased, three bladed propellers incorporate supercritical airfoil sections and have a fuselage clearance of approximately .14 times the prop diameter. Operating at 1500 RPM during cruise conditions, the blade passage frequency is calculated to be 75 Hz and the tip speed 692 ft./sec. This particular aircraft model has provisions for a 6.8 psi differential cabin pressure to allow for a 10,000 ft cabin environment at its 35,000 ft operational ceiling. The combination of this pressure differential together with a rectangular shaped cross section of the fuselage structure dictated a relatively thick aluminum skin of .064 in. The passenger cabin includes five double windows on each side of the fuselage with the outer pane having an outward curved surface. The cabin height is 4.76 ft, and the length is 17.5 ft.

To determine the insertion loss of a particular acoustic treatment two separate flights were required, one flight without the treatment and a second flight with the treatment installed. In order to attribute the change of interior noise

level between the two flights to the acoustic treatment, an attempt was made to hold constant other factors that could influence measured interior noise level. Such factors include engine power and RPM, air speed, altitude, cabin pressure, aircraft weight, microphone position, and cabin configuration (other than sidewall acoustic treatment).

For the tests reported here, the aircraft was operated at 16,000 ft altitude with both engines set at maximum continuous power and 96 percent RPM. These settings resulted in an indicated airspeed of 214 knots and blade passage frequency of 76.35 Hz. The cabin pressure was set at a value equivalent to an altitude of 2300 ft. Acoustic instrumentation to verify repeatibility of the exterior acoustic sound pressure levels was not included on these flights. However, previous tests with a similar aircraft (ref. 1) indicate that propeller exterior noise is repeatable from test to test using only pilot instruments such as airspeed, engine power, and propeller RPM indicators to establish test conditions. The propeller synchrophaser was operating in its normal cruise condition.

Acoustic Treatment

Flight test results are reported here for three acoustic treatment configurations. These tests were carried out using an engineering support aircraft for the purpose of evaluating various acoustic treatment configurations; therefore, the cabin did not contain standard sidewall treatments or cabin furnishings. Configuration 1 is referred to as untreated or bare, and had no acoustic or thermal treatment on the cabin walls and no carpet on the floor. The cabin contained four seats (pilot, copilot, and two passenger seats) for the 'untreated' as well as the 'treated' tests. Configuration 2 had two layers of one inch thick AA fiber fiberglass of .072 lb/ft^2 each, with a silvered-mylar septum on the side facing the cabin interior, applied to all sidewall surfaces except the floor, windows,

firewall, and instrument panel. The third treatment configuration selected for test for reference purposes is referred to as the 695A treatment. This configuration used a combination of layers of damping tape, fiberglass, mass-loaded vinyl septa, and a foam-and-rubber sandwich noise barrier. The combination used varied with location on the sidewall. Figure 2 illustrates the treatment used in the propeller plane region of the cabin, and figure 3 indicates the treatment used in various sidewall regions.

Data Measurement and Analysis

Cabin noise in flight was measured using two entirely separate instrument systems. Microphone positions for system 1 are shown in figure 4. These positions correspond to the passenger positions in a furnished cabin, and the microphones were all located at ear level for a seated passenger. System 2 included microphones located about 3 inches inboard of positions 3, 4, 5 and 6. For the bare cabin configuration both systems were operated at the same time, and data was recorded on both systems during the same few minutes of stabalized flight conditions. For the 695A treatment configuration each system was used on a separate flight test, separated by a few days. System 2 was not used for the fiberglass treatment configuration. For both systems, the microphone signals were recorded on tape and analyzed later in the laboratory. The two systems used different microphones, signal conditioning, tape recorders, and data analyses equipment, and were operated by different personnel.

For system 1, the conditioned microphone signals were recorded directly on an 8-channel FM recorder with no frequency weighting. The tape recorded data was analyzed using a commercially available narrowband spectrum analyzer. Analyzer settings resulted in a 6 Hz bandwidth over a frequency range from 0 Hz to 1000 Hz using a Hanning window and 64 averages. Typical record length was 30 seconds.

For the data presented here the frequency spectra were A-weighted just prior to plotting. Examination of calibration information indicates that the instrumentation noise floor is at least 10 dB below the data at the frequencies considered here.

For system 2, acoustic data were recorded on six channels of a 7-channel FM tape recorder, and the seventh channel was used for voice annotation. Tape speed was 7.5 inches per second and bandwidth was 5 kHz. For some tests instrumentation amplifiers were used to provide switchable gain and signal level indicators. Data were reduced in one-third octave or narrowbands using a commercially available, single channel, spectrum analyzer. One-third octave band analysis covered the frequency range to 20,000 Hz. Narrowband analysis was performed in the frequency range 0 Hz to 1000 Hz, with a frequency resolution of 2.5 Hz and an effective noise bandwidth of 3.75 Hz. Data sample lengths were usually 32 seconds.

For this report, initial data analyses considered narrowband spectra of A-weighted noise level such as shown in Figure 5. The two spectra in figure 5 were measured in two separate flights, each flight having a different sidewall treatment. The microphones were installed at fixed positions and flight conditions were carefully established in an attempt to maintain the same test conditions for both flights, so that the difference in level between the two spectra would result only from the difference in treatment. For this study, then, the treatments are characterized by their insertion loss, which is defined as the reduction of noise level that results from the insertion of the treatment when all other factors are held constant. Insertion loss was determined graphically, as indicated in figure 5, and is a function of frequency, microphone position, initial configuration, and final treatment. Note that insertion loss is positive when the treatment reduces the level, but can also be negative, as it is at the 150 Hz tone in figure 5.

Insertion Loss in Flight

Insertion loss values calculated from flight measurements for six microphone positions and three treatments are shown in figures 6, 7, and 8. Values determined at the distinct peaks, corresponding primarily to propeller tones at about 75 Hz and multiples, are indicated by the symbols, and the values determined at frequencies between the tones are shown by the lines. Occasionally, tones at the propeller shaft frequency (25 Hz) and the engine frequency (670 Hz) also appear.

Insertion loss of 2 inches of fiberglass relative to no treatment is shown in figure 6. Figure 6 shows that the insertion loss at the propeller tones can vary widely for different positions in the aircraft. For example, at the 150 Hz tone the insertion loss varies from about 8 dB at positions 1 and 6 to about minus 8 dB at position 4. A similar amount of variation is observed at the 225 Hz tone. Note that the negative value of insertion loss means that the noise level at that position and frequency was higher when measured with the fiberglass treatment, whereas the intent of adding fiberglass is to reduce the noise level. The tones at 150 and 225 Hz are important because they are major contributors to the overall noise level, as suggested by figure 5. The insertion loss at the other tones are positive, in general, but also vary in magnitude by substantial amounts.

The magnitude of the variability was not anticipated in planning the tests, therefore, no special instrumentation or procedures were used to ensure precise repetition of test conditions or instrument settings such as synchrophaser knob position. The reasons for the variability are not fully understood, therefore, but may include interactions between the noise fields of the two propellers, changes of the acoustic-modal characteristics of the cabin associated with the wall impedance of the inserted treatment, or variations in the contribution from structureborne noise. The reasons should be sought out and understood so that the

treatment can provide maximum benefit for all passenger seat positions. Investigation of the variability is outside the scope of this paper because the emphasis here is on the treatment and not on the other factors. Treatment insertion loss will be studied using average tone values and broadband values between the tones.

The insertion loss given by the lines represents values associated with the broadband component of the spectrum. The broadband cabin noise is thought to result from the fuselage boundary layer noise transmitted through the fuselage sidewall. This conclusion is based on observed variations of the broadband level with test condition and acoustic treatment, and comparisons with predicted exterior noise levels due to boundary layer flow (Appendix A). Figure 6 shows that the variation of broadband level with position is generally much less than for the tones. Superposition of the broadband curves suggests that the variability is generally within $\pm$ 4 dB, compared with the tone variability of about $\pm$ 8 dB. The broadband insertion loss in figure 6 suggests a reasonably well defined trend of increasing insertion loss with frequency.

Figure 7 shows the insertion loss of the 695A treatment relative to the untreated sidewall configuration. The variability of the tones and the well defined trend of broadband insertion loss with frequency are similar to the results shown in figure 6 for the fiberglass treatment. However, figure 7 shows that the broadband insertion loss tends to be lower at the two forward positions than at the aft positions.

Figure 8 shows the insertion loss of the 695A treatment relative to the fiberglass treatment. Results for the six positions shown in figure 4 are superimposed in this figure. Figure 8 shows that the large variability of the tone values is still present, which indicates that the variability does not result solely from the lightly damped and reverberant acoustic properties of the bare cabin.

It is of interest to examine the insertion loss of the tones and broadband components separately, and in one-third octave bands, for the following reasons. The tones are of primary interest because they dominate the low frequency spectrum, and the acoustic treatment was designed to take advantage of the localized space distribution of the propeller field. However, the tones provide values only at discrete frequencies, and have such scatter as to make reliable comparisons with lab data difficult. The broadband noise provides values at most frequencies, has less scatter, and would dominate the cabin noise if control methods were used that reduced only propeller tone noise. One third octaves more accurately represent subjective response, and the lab is calibrated to provide acoustic data only in one-third octave form.

The separation of tones from broadband was accomplished graphically, as indicated in figure 9. A curve was drawn through the broadband part of the spectrum, cutting off the tone peaks, and the curve was integrated over each one-third octave band. Resulting interior noise levels are shown in figure 10 for the bare cabin and in figure 11 for the 695A treatment. The data for system 1 show the broadband values at four cabin positions. The data shows a systematic variation with frequency, with relatively small variation with position. The vertical lines indicate one-third octave cabin noise levels obtained from data system 2. The horizontal tic marks on each line indicate values measured about 3 inches inboard of system 1 microphones at positions 3-6 shown in figure 4. For the bare aircraft both systems were in operation at the same time and data was recorded virtually simultaneously. Examination of the narrow band spectra showed that each one-third octave band marked with an arrow does not contain any propeller tones. Figure 10 shows that data system 2 values are about 3 dB higher than system 1 values in these bands.

The relative contributions of propeller and boundary layer noise sources can be seen in figure 10. Comparing the data from the two measurement systems indicate that the propeller dominates the frequency bands at 80 Hz and from 160 Hz to 315 Hz, whereas the boundary layer noise dominates at 400 Hz and higher. The noise levels in the propeller dominated bands are only slightly higher than in the boundary layer bands. This suggests that control techniques that reduce only the propeller noise (such as propeller source noise reduction) would result in relatively small reductions of overall A-weighted cabin noise level.

Cabin noise spectra from the two measurement systems are shown in figure 11 for the 695A treatment. The measurements with each system were made on separate flights; but with nominally the same test conditions. In the bands without tones system 2 shows noise levels that are about 3.5 db higher. For this treatment configuration also, the propeller tones dominate only the 80 Hz and 160 to 315 Hz bands, but in this case the levels are substantially higher than the boundary layer noise levels in the 400 to 800 Hz bands. This suggests that additional noise reduction is required in the propeller dominated bands.

Insertion loss of the treatment was determined in one-third octave bands using the data shown in figures 10 and 11. For the broadband - only data (the symbols for system 1) the noise level "treated" (fig. 11) was subtracted from the "untreated" level (fig. 10) for each cabin position. For the broadband plus propeller (system 2) the noise levels were averaged over cabin position before subtracting. The resulting insertion loss is shown in figure 12. This figure shows that in the frequency bands below 500 Hz the treatment provides less insertion loss for the total noise (propeller and broadband) than for the broadband component alone. The data of figure 12 and insertion loss of the 2 inches of fiberglass vs bare treatment are compared with laboratory data in a later section of this paper.

LABORATORY RESULTS AND COMPARISON WITH FLIGHT

Laboratory Tests

Noise transmission characteristics of a panel and several treatments representing the aircraft of this study have been measured in the Transmission Loss Apparatus at Langley Research Center. The T L Apparatus is described in reference 2 and the test results are presented and discussed in reference 3. A brief summary is given here.

Test Setup

To experimentally establish the noise transmission loss characteristics of the test structure and the add-on treatments, the aircraft panel is mounted as a partition between two adjacent reverberant rooms which are designated source room and receiving room. A schematic plan view of the transmission loss apparatus is depicted in figure 13. In the source room, which measures 11 by 12 by 12.9 ft, a diffuse field is produced by two reference sound power sources. Sound from the source room is transmitted into the receiving room only by way of the test panel, which has a sound exposed area of 45.25 by 57.5 in. The test panel is accommodated by a steel and rubber mounting frame, which is designed for minimum acoustical and structural flanking. A space and time average of the sound pressure levels in each of the rooms is accomplished by means of a windscreen-covered microphone mounted at the end of a 35.8 in. long rotating boom which has a rotational speed of 1/16 revolutions per second. The microphones complete two full rotations during the 32 seconds linear time averaging analysis which is performed by a digital one-third octave band frequency analyzer.

All tests referred to in this report were carefully monitored to have practically identical test conditions and results are believed to be accurate within the range $\pm$ 2 dB for frequency less than 200 Hz, and within $\pm$ 0.5 dB for frequency greater than 200 Hz. The addition of treatments to the panel structure on the

receiving room side alters the room absorption. To account for this, the treatment was applied to the wall of the receiving room opposite the test panel in a separate test, thus not changing the transmission loss of the test structure but only the absorption characteristics of the room. A correction was needed to account for the use of one or more layers of fiberglass treatment. Corrections for other treatments did not affect the transmission loss by more than .5 dB and for that reason are not applied to the test results. All data reported in this document are corrected for the additional absorption due to fiberglass applications.

Test Panel and Treatment

The test panel structure was chosen to be modeled after a fuselage section that includes the propeller plane and two windows. Due to the small curvature of the actual fuselage and because of ease of construction and analyses, the laboratory model is flat and covers an area of 47.5 in. (the approximate cabin height) by 59.5 in. Figure 14 shows the designated area and its location on the fuselage, and figure 15 shows a photo of the test panel with some of the treatment installed. In the aircraft, doublers were used to reinforce the structural members of the frame in the area near the propeller plane. In the laboratory panel structure this was achieved by the addition of solid straps with a thickness equal to the total thickness of the doublers. Windows were not installed in this test panel in order to study transmission through structure and treatment without other complicating factors. The window bays (A and C in fig. 15) had the same skin thickness and treatment as the other bays, for most tests. The stiffener members of the test panel, which have a depth of 2 in, extend onto the supporting frame of the transmission loss apparatus.

Candidate treatment packages for designated parts of the fuselage of the aircraft were tested in the transmission loss apparatus. The thickness and area

density of each of the elements is given in Table 1. Figure 16 shows the different layers of the treatment as used in the transmission loss tests where the first six layers are squeezed into the space between the stiffeners, having a total depth of 2 in. The total surface mass of the heaviest treatment combination equals about 2.2 lb/ft^2. Results including a trim panel (shown in fig. 16) are reported in reference 3 but not here since the flight configurations did not include a trim panel.

The vibration damping tape is designed to damp resonant vibrations in sheet metal by converting vibrational energy to heat. The damping tape used here is a pressure sensitive, compounded polyurethane damping foam with an aluminum foil laminate backing. It is resistant to moisture, solvents, aging and fatigue.

The acoustic blankets are composed of glass fibers with a nominal diameter of 1 micron. They provide sound attenuation partly by acting as a reflective surface and partly by conversion of the acoustic energy of the sound that penetrates the material to heat by viscous losses in the interstices. They are also used for the purpose of thermal insulation.

The vinyl septa are made of a mass loaded vinyl fabric, reinforced with fiberglass to provide noise transmission loss in a limp material. It is corrosion resistant to acids, mild alkalis, oils and greases.

The noise barrier is a composite of a loaded urethane elastomer chemically bonded to a decoupler foam. The urethane elastomer functions as the noise barrier while the decoupler foam serves to isolate the barrier from the vibrating surface. It features a broad operating temperature range and is resistant to aging. The barrier layer is covered with a 2 mils. thick protective polyester film facing.

Figure 15 shows the test panel mounted in the supporting frame of the transmission loss apparatus with part of the acoustic treatment installed. Panels A,

B, and E show vinyl septum 2, panel D is covered with vinyl septum 1, acoustic fiberglass blankets are installed behind panels C, F, G, and H, and the aluminum foil of the damping tape is visible on panels K and L.

The type of material, dimensions and installed configuration of the treatments used in the lab were the same as in flight with the following exceptions. The vinyl septa used in flight were both of .31 lb/ft^2 density, but the septa used in the lab were of slightly different density as shown in Table I. The fiberglass blankets used in flight had lightweight silvered-mylar glued on one face; the lab tests did not include this mylar. In the aircraft, the fiberglass blankets are wrapped around the vinyl septa leaving a space between the ends of the septa and the fuselage frame, as shown in the sketch in figure 2. In the lab, each layer of fiberglass or septum was cut to lay flat and to fill the space between the frames, as sketched in figure 17.

Laboratory Results

Laboratory results from five configurations were used for comparison with flight results. Transmission loss for four configurations is shown in figure 18. For the bare structure the T L was calculated from field incidence mass law. These values were used instead of measured data because the measured T L exhibited several "dips" that are thought to be associated with the boundary conditions of the panel in the lab setup, and would not be expected to occur on the aircraft. When damping tape was applied to the skin panels the "dips" disappeared and the TL followed the mass law for mass of skin plus damping tape (ref. 3). The curve labeled "roof" in figure 18 is intended to represent the roof region in figure 3, "aft sidewall" the region aft of station 154.5 in figure 3, and "prop-plane sidewall" the region between stations 78 and 154.5. The treatment elements described in Table I were arranged for these configurations as shown in figure 17. The TL of the fifth configuration, "2 inches of fiberglass," was determined from tests

using the panel with damping tape applied. The change of TL was determined by comparison of results with and without the fiberglass present. As shown in figure 20, the fiberglass provides increased TL only above 400 Hz. The values above 400 Hz are felt to be within 2 dB of values appropriate for use when the fiberglass is added to the bare panel (as in the aircraft).

Prediction of Insertion Loss

The insertion loss of a treatment is composed of two parts; the change of sidewall noise transmission and the change of absorption of the noise in the cabin. For a sidewall having different treatments on different sidewall areas such as shown in figure 3, the effective TL of the total sidewall is calculated from

$$TL_{EFF} = -10 \log \left[A_{ROOF}\, 10^{\frac{-TL_{ROOF}}{10}} + A_{AFT}\, 10^{\frac{-TL_{AFT}}{10}} + A_{PROP}\, 10^{\frac{-TL_{PROP}}{10}} \right], \quad (1)$$

where the areas are a proportion of the total area. For the 695A treatment

A_{ROOF} = roof area/total area = .106

A_{AFT} = area of aft sidewall/total area = .447

A_{PROP} = area of sidewall in prop plane/total area = .447,

and the TL values of the different regions are taken from figure 18. For this calculation the windows are ignored, so there is an implicit assumption that each window has the same TL as the adjacent wall. Windows are discussed further in a later section of this paper.

The treatment insertion loss, IL, is found from

$$IL = \Delta TL + \Delta ABS.$$

The change of transmission loss, ΔTL, is found by subtracting the TL of the bare structure from the effective TL, TL_{EFF}, of the treated sidewall. The change of absorption, ΔABS, is found from

$$\Delta ABS = 10 \log \left[\frac{\alpha_{e,\ treated}}{\alpha_{e,\ untreated}} \right] \qquad (2)$$

where the effective absorption, α_e, is found from

$$\alpha_e = \frac{\sum A_i \ \alpha_i}{A_{TOTAL}} \ , \qquad (3)$$

where A_i = area of individual surface

α_i = absorption of individual surface

A_{TOTAL} = total area

For the aircraft of this study, with absorption treatment on the sidewalls, roof and aft bulkhead but not on the floor or forward wall (the cockpit and windshield) the effective absorption is given at each frequency by

$$\alpha_e = .26\ \alpha_{i,\ untreated} + .74\ \alpha_{i,\ treated}.$$

For untreated surfaces α_i is taken as 0.1 based on data presented in reference 4, therefore the bare aircraft has $\alpha_e = 0.1$. For treated surfaces the absorption was determined by the thickness of the fiberglass layer exposed to the cabin interior and backed by either a vinyl septum, the noise barrier, or the sidewall structure. The absorption values used for the fiberglass are shown in figure 19. These values, taken from reference 5, were determined by the manufacturers using standardized test facilities and procedures. As an approximate check, the absorption values of the fiberglass blankets used in this study were measured in the receiving room. The values were acceptably close to values presented in reference 5 for a test setup similar to the one used here.

Comparison of Flight and Lab Results

Insertion loss of the 2 inches of fiberglass treatment compared to no treatment was predicted using lab results, and the comparison with measured flight insertion loss is shown in figure 20. The flight data is presented for four positions at mid and aft cabin, and was determined for the broadband (boundary layer)

component only, as described previously. Agreement between predicted and measured results is shown to be good at frequencies above 100 Hz. Below 100 Hz the flight data may be inaccurate due to the difficulty of graphically fitting a curve to the steeply sloping narrow band spectra at these frequencies (fig. 9). In the important frequency range of 160 to 400 Hz where the highest A-weighted noise components occur, figures 5 and 11, the contribution of TL is seen to be negligable, while the absorption results in insertion loss values from 2 to 8 dB.

Predicted insertion loss for the 695A treatment compared to no treatment is compared with flight results in figure 21. Predicted values are given for two cases, one including only roof and prop plane TL in the effective TL, and the second including aft sidewall in addition. Predictions were made for both cases with the thought that cabin absorption might restrict the noise that enters at the rear of the cabin from reaching the more forward positions 3 and 4. However, the flight data shows that the Insertion loss is about the same for all four cabin locations. The predicted insertion loss including roof, prop plane and aft sidewall TL is seen to be in good agreement with the flight data at frequencies from 125 Hz to 315 Hz. The overprediction at frequencies below 100 Hz is thought to result from boundary condition stiffness of the panel in its facility mounting. The reason for the overprediction at frequencies above 400 Hz has not been determined, but may be due to flanking acoustic transmission through lightly treated sidewall locations, or through windows.

Possible approaches to improved treatment are illustrated in figure 22. The absorption associated with the 695A treatment as tested here is indicated by the dot-dash line labeled "1 in. AA." Reference 5 indicates that substantially larger values of absorption can be obtained by using fiberglass of a different type or larger thickness. Using the higher absorption values from reference 5 the ΔABS contribution has been estimated and is shown as the dotted line labeled "High α".

Increases of 3 to 4 dB are shown at frequencies from 160 to 400 Hz. In order to obtain cabin noise reductions from this approach the fiberglass must be exposed (in the acoustic sense) to the cabin interior, and not covered with an acoustic barrier such as a vinyl layer or a trim panel.

The contribution of the increased effective TL of the 695A treatment is shown by the dashed line. This curve indicates the effective ΔTL when the TL contributions of roof, aft sidewall, and prop-plane sidewalls are combined using equation (1) and the individual TL value from figure 18. Increased ΔTL could be obtained by extending the prop-plane treatment forward and aft so that its larger ΔTL contribution, indicated by the solid line, would not be reduced by flanking transmission through the more lightly treated forward and aft sidewalls. Other treatment approaches are also possible.

Windows

As previously mentioned, the calculation of the effective TL of the sidewall using equation (1) assumes that the window TL is equal to the TL of the adjacent sidewall. This assumption was made because of the difficulty of determining a reliable TL value for the windows. The window construction, illustrated in figure 23, includes two panes of plexiglass, one of which is curved, with a rubber spacer between the panes. No experimental data is available for this configuration, and available theoretical results, reference 6, are for a window of different dimensions and are not in the form of TL required for combination with the test data for the treated sidewall.

As a rough approximation the window can be modeled as a single pane of thickness equal to the sum of the two panes, or as a pair of parallel panes of infinite extent. Theoretical TL for these two models is shown in figure 24. Comparison with figure 18 indicates that up to 200 Hz the calculated window TL is equal to or

more than the sidewall TL. Above 200 Hz the window TL can be substantially less than the sidewall TL depending on frequency and on which window model is considered.

CONCLUDING REMARKS

This paper describes a flight and laboratory study of sidewall acoustic treatment for cabin noise control. To focus attention on the treatment effects, results are presented as insertion loss (IL), defined as the reduction of cabin noise level at a specific location that occurs when a treatment is added and all other test conditions are held constant.

In flight, cabin noise levels were measured at six locations with three treatment configurations. The aircraft was operated in normal twin engine cruise at 16,000 ft altitude with cabin pressurization equivalent to an altitude of 2300 ft. IL values at the propeller tones were found to vary by $\pm$ 8 dB depending on position in the cabin, while the broadband (boundary layer) levels have the smaller variability of $\pm$ 4 dB. Broadband noise levels from narrow-band analysis are reduced to one-third octave format separately from the tones, and IL values from this boundary layer noise component are shown to be several dB higher than IL values of the total noise signal including both tones and boundary layer noise.

Laboratory tests were carried out using a specially constructed structural panel modeled after the propeller plane section of the aircraft sidewall, and acoustic treatments representing those used in flight. Transmission loss and treatment absorption values for various configurations representing the different treatments used on different aircraft sidewall areas were measured. These lab values were combined using classical acoustic procedures to obtain a prediction of IL. Comparison with IL values measured in flight for the boundary layer component of the noise indicated general agreement.

APPENDIX A

ESTIMATION OF EXTERNAL BOUNDARY LAYER NOISE

In order to evaluate the fuselage boundary layer as a source of the broadband interior noise, exterior noise spectra were calculated for several flight conditions and the variations with flight conditions were compared with measured variations of interior noise.

The exterior noise was calculated using the method of reference 7 for a position 18 ft from the nose of the aircraft. This position is at the same longitudinal station as microphones 5 and 6, shown in figure 4. Aircraft altitude and indicated airspeed were determined from pilot instruments, and atmospheric properties (viscosity, density, Reynolds number) were determined using standard atmosphere tables, reference 8. Calculated noise spectra are shown in figure 25 for two flight conditions. The shape of these spectra is quite similar to the shape of the measured interior spectra shown in figure 5, both being approximately flat at high frequencies and dropping off sharply at low frequencies (because of the A-weighting). The measured interior levels drop off slightly at higher frequencies whereas the predicted exterior levels increase slightly at the higher frequencies. This difference could be expected because of the increase of transmission loss with increasing frequency associated with the fuselage sidewall.

Figure 25 shows that the predicted exterior noise level is lower by about 4 dB at 29,000 ft altitude compared to 16,000 ft altitude. In addition, the cabin pressure at 29k ft (equivalent to 8,000 ft altitude) is lower than the cabin pressure at 16k ft (equivalent to 2,300 ft altitude). The reduced acoustic impedance inside the cabin at the higher altitude is estimated to reduce the noise radiated into the cabin by about 1 or 2 dB. The combined effect of these two factors is a reduction of 5 or 6 dB of interior noise at the higher attitude. Comparison of

measured cabin noise levels for the two altitudes for each of the six microphone position's indicated a lower level by 6 to 8 dB at the higher altitude. For flight at a given altitude, both the predicted exterior noise and the measured interior noise indicated virtually no variation of level with flight speed for the available range of flight speed. In addition, the predicted exterior levels are higher than the interior levels, as would be expected to result from the noise reduction of the sidewall structure. In view of the approximations involved, these results are consistent with the estimated effects associated with the fuselage boundary layer noise.

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TABLE I.- ACOUSTIC TREATMENT ELEMENTS USED IN
LABORATORY NOISE TRANSMISSION TESTS

Element	Thickness, in.	Area Density, lb/ft^2
Skin	0.063	0.95
Total Structure	2.31	2.06
Damping Tape	0.25	0.316
Fiberglass	1.0	0.05
Vinyl Septum 1	0.04	0.367
Vinyl Septum 2	0.024	0.281
Noise Barrier	0.325	1.016
Heavy Treatment (695A)	3.31	2.174

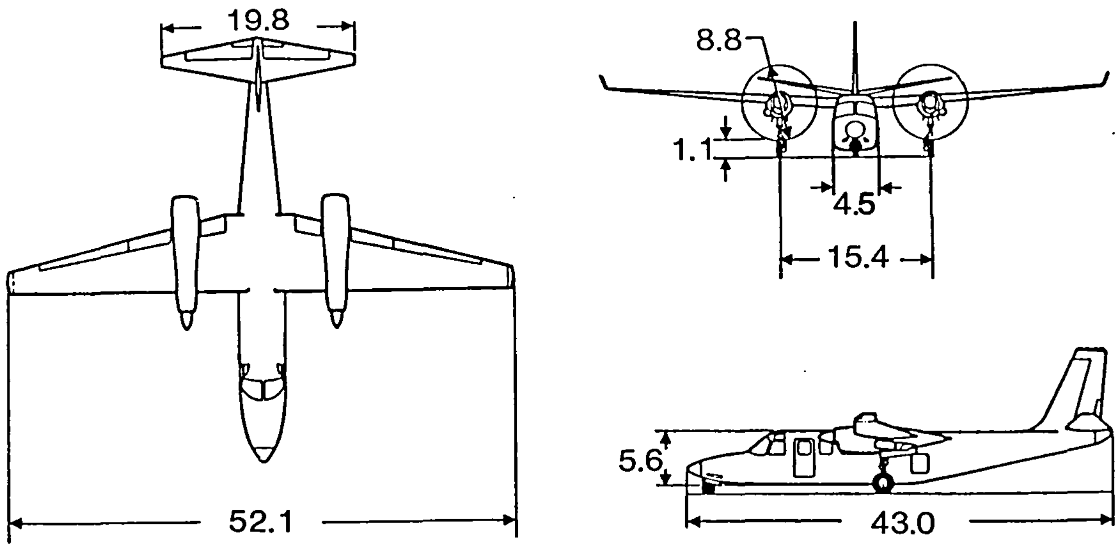

Figure 1.- Aircraft used in treatment study.
Dimensions in feet.

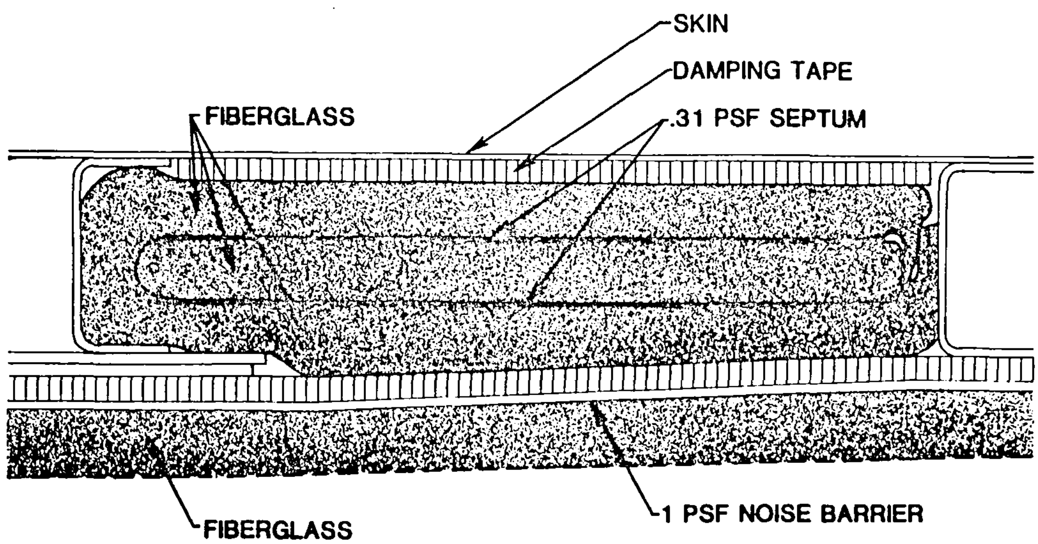

Figure 2.- Typical section through wall and acoustic treatment in area of the prop plane.

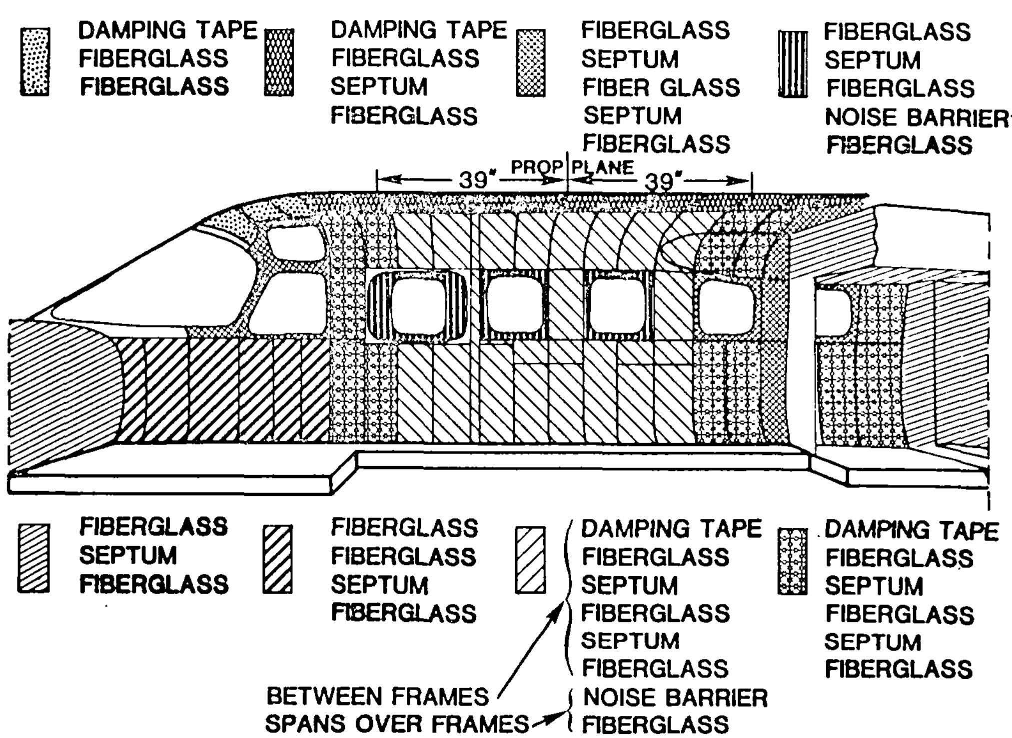

Figure 3.- Distribution of treatment in 695A configuration.

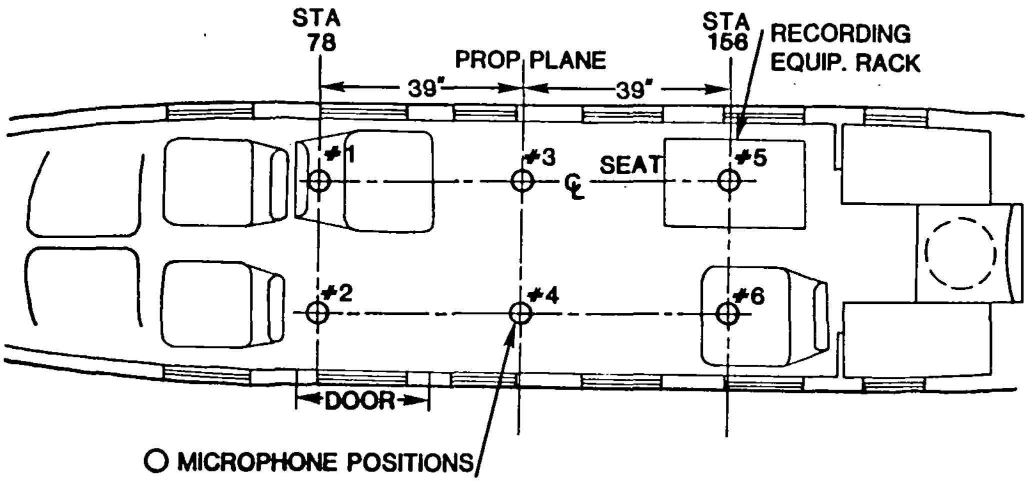

Figure 4.- Cabin arrangement and microphone positions for treatment flight study.

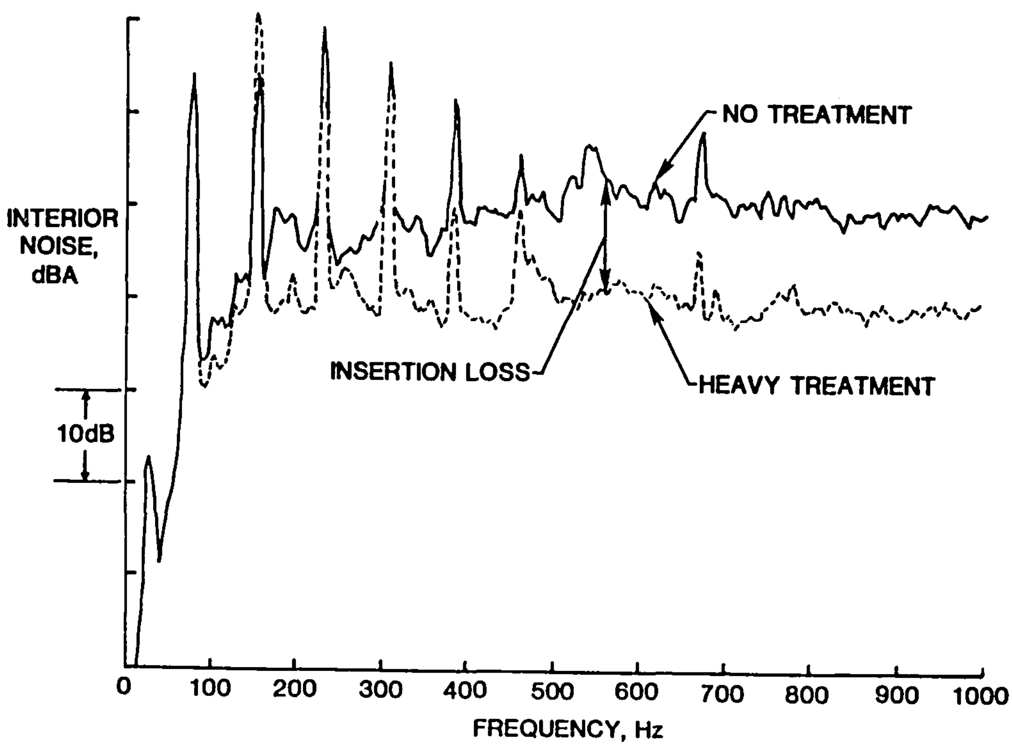

Figure 5.- Cabin noise measured in flight at position 2 for two treatments.

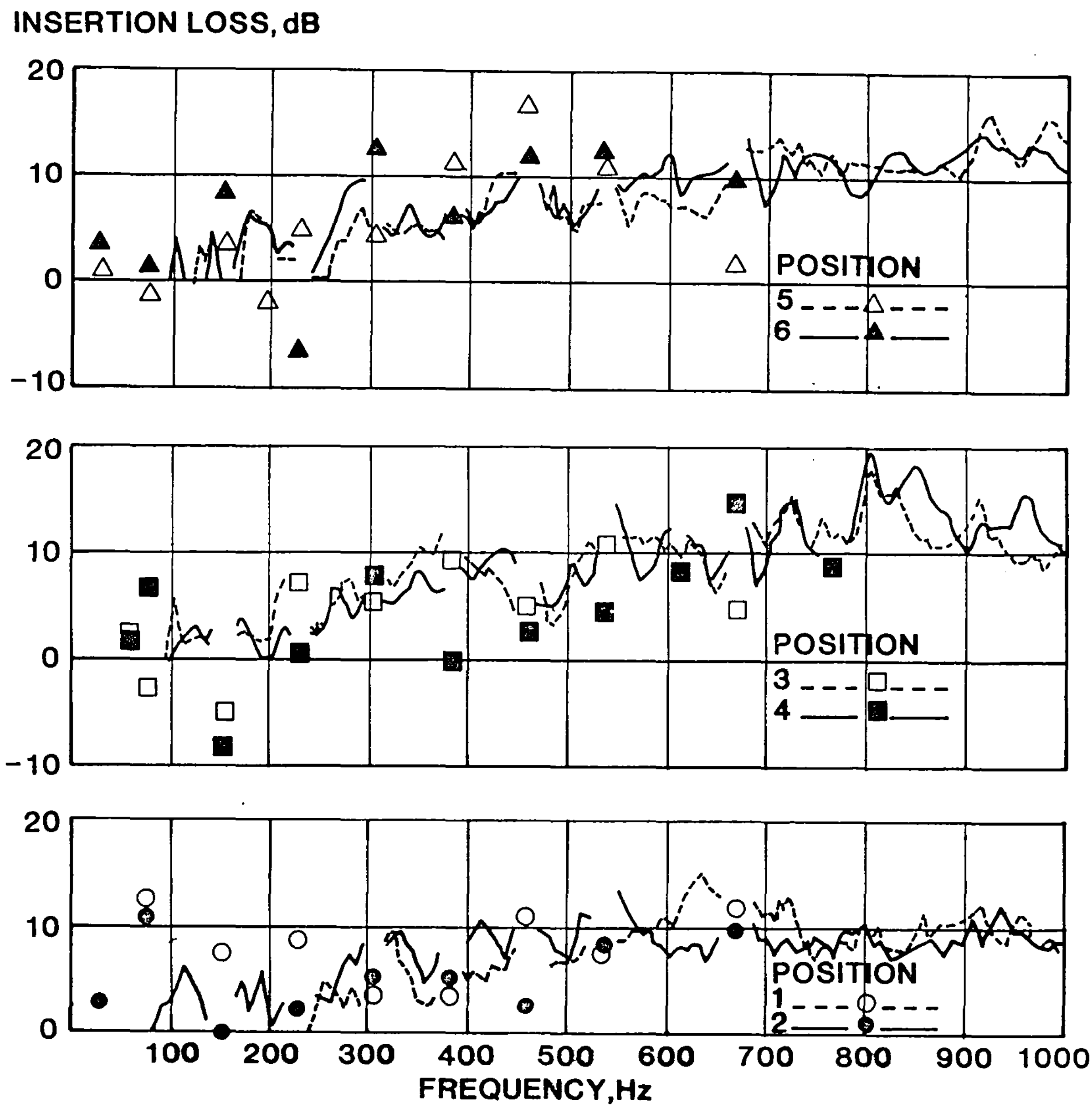

Figure 6.- Insertion loss of 2 in. of fiberglass relative to no treatment. Narrow band flight data.

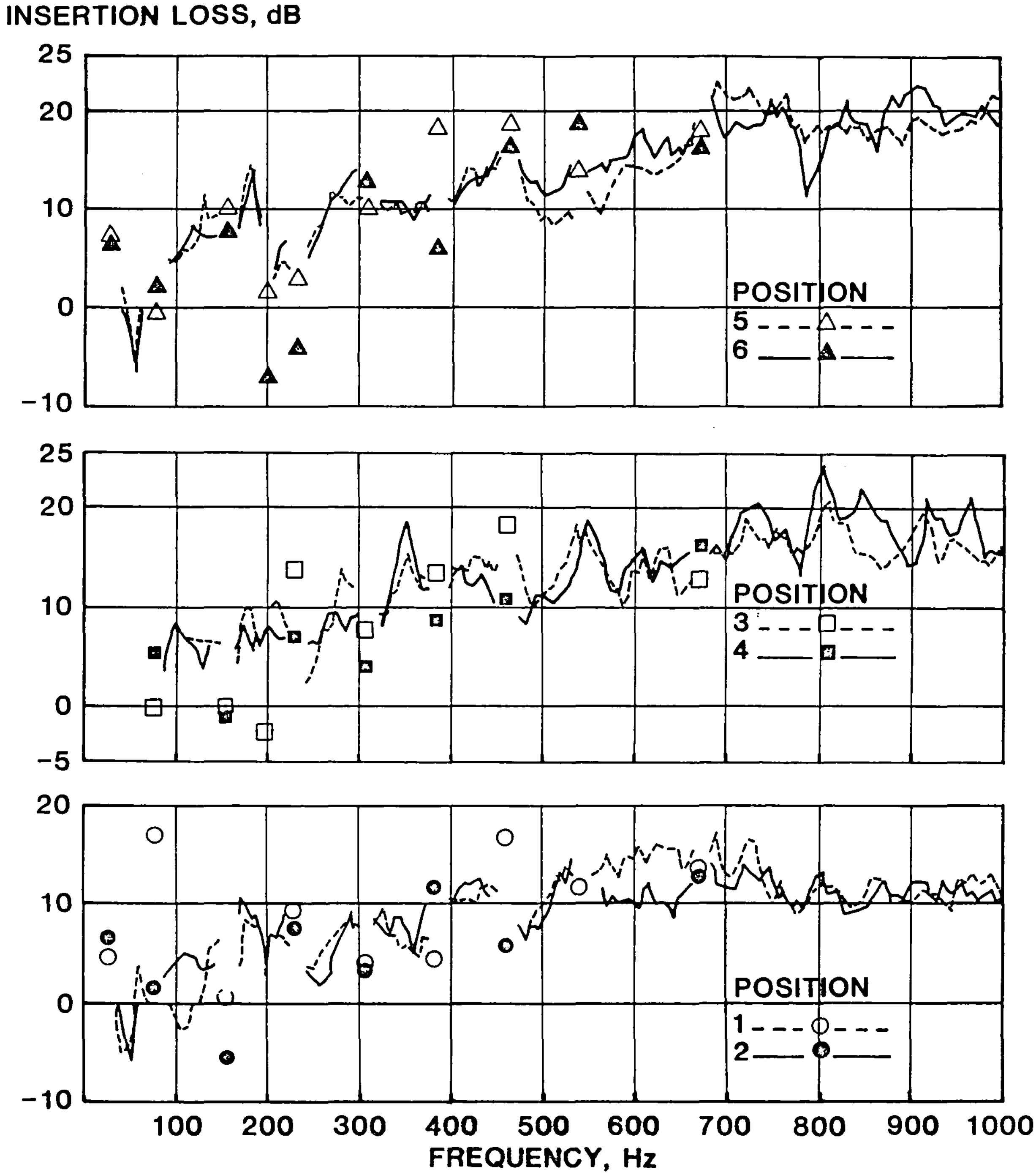

Figure 7.- Insertion loss of 695A treatment relative to no treatment. Narrow band flight data.

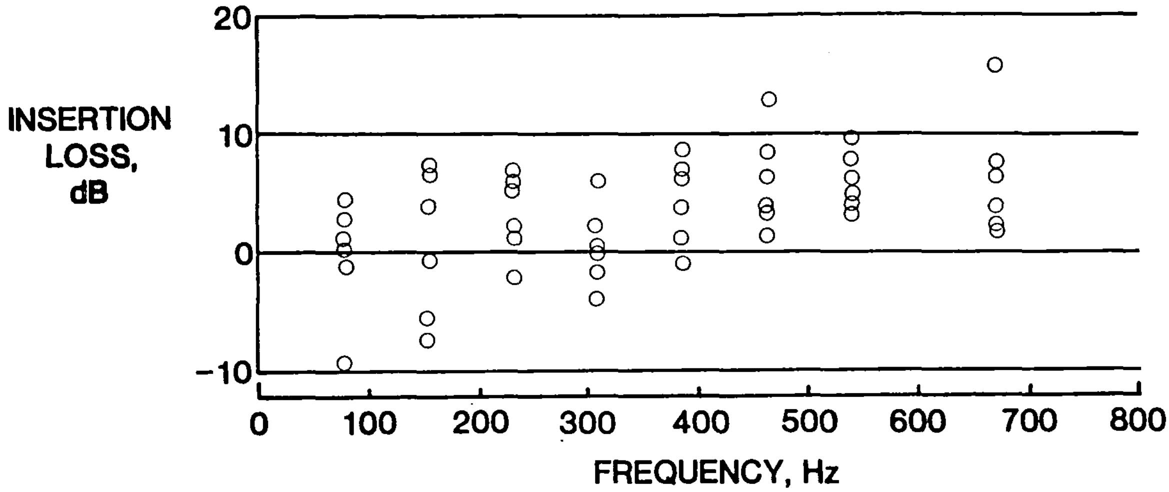

Figure 8.- Insertion loss of 695A treatment relative to 2 in. of fiberglass. Flight data, propeller tones only.

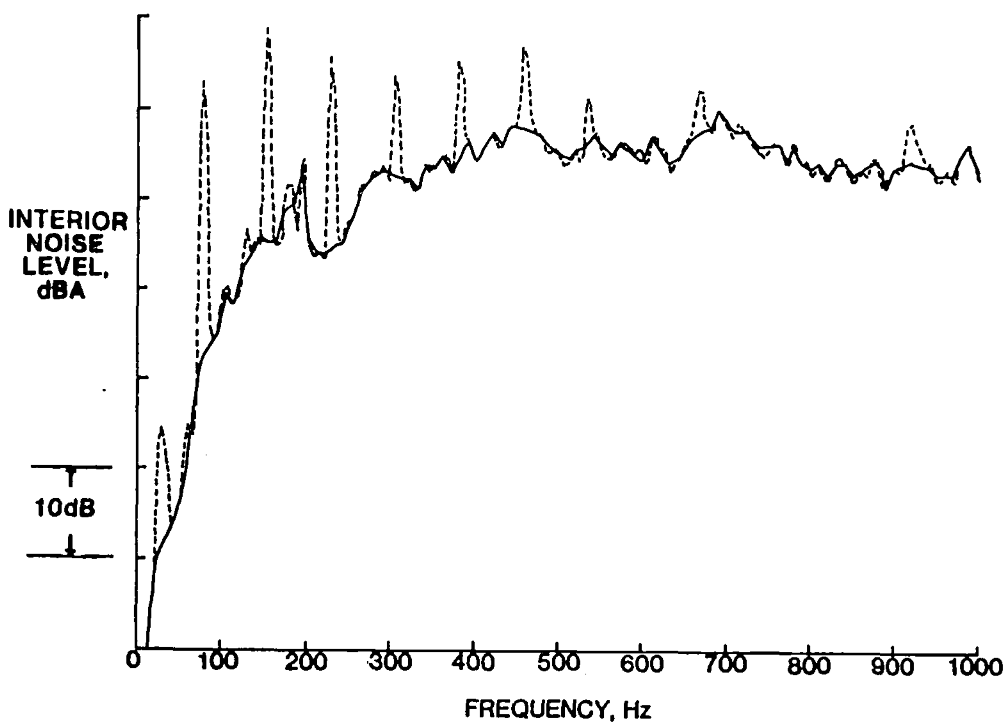

Figure 9.- Curve fit for conversion of narrow-band data to one-third octave data without tones.

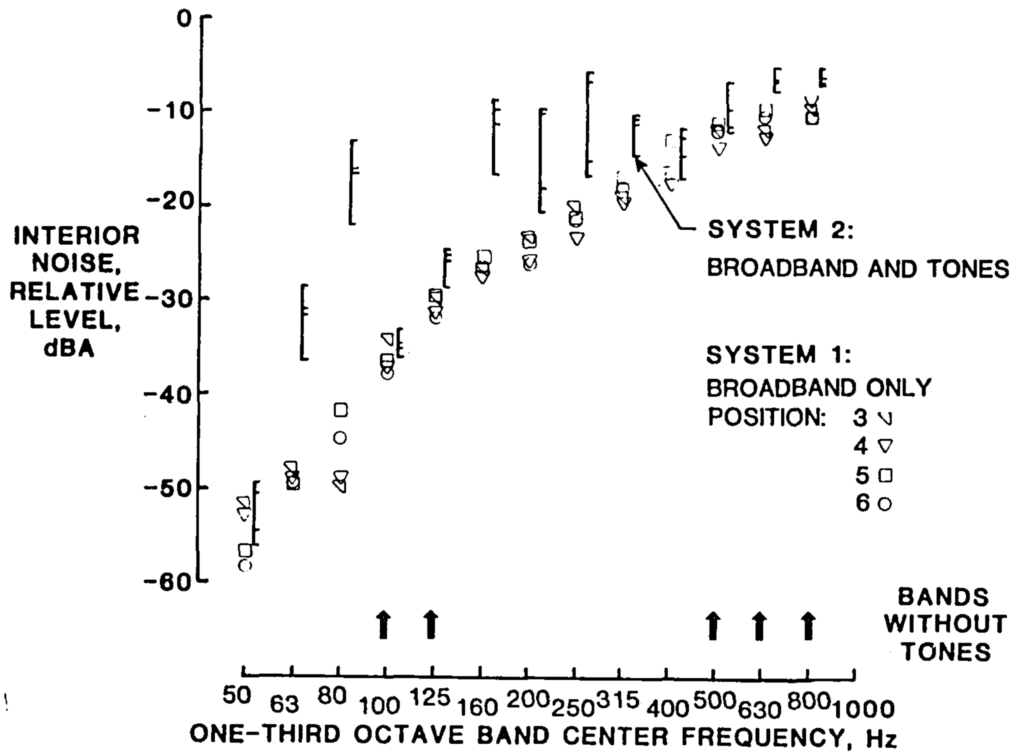

Figure 10.- Interior noise in flight from two measuring systems, untreated cabin.

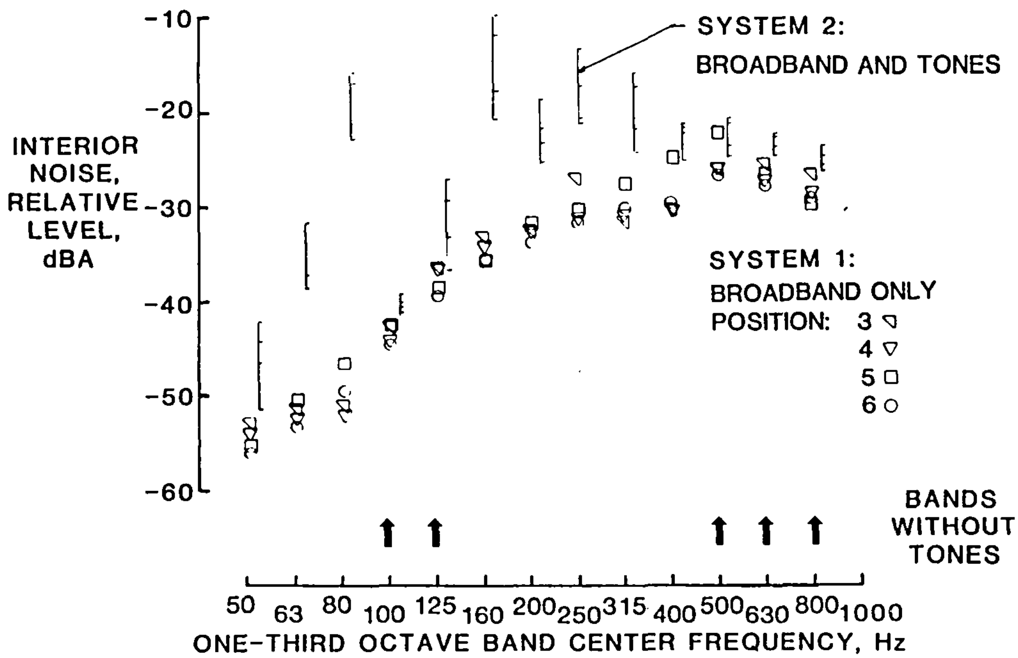

Figure 11.- Interior noise in flight from two measuring systems, cabin with 695A treatment.

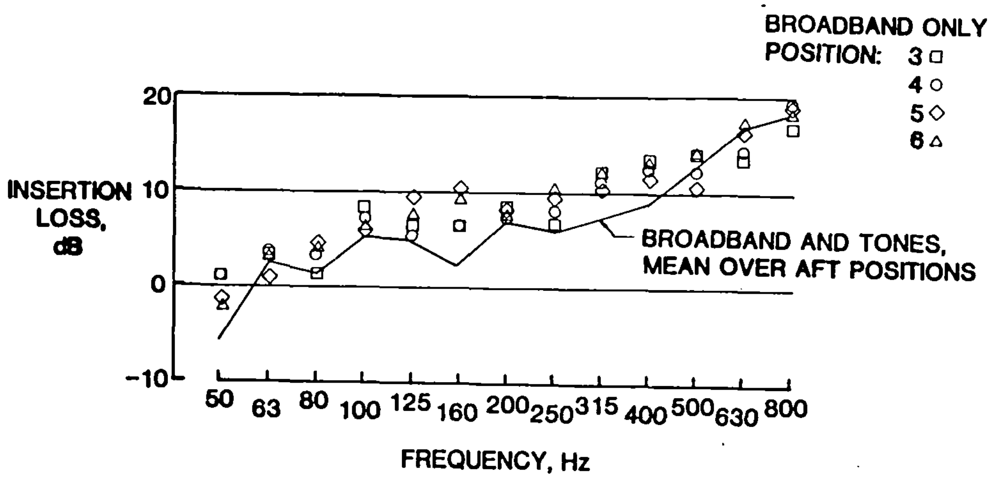

Figure 12.- Insertion loss of 695A treatment relative to no treatment, flight data in one-third octave bands.

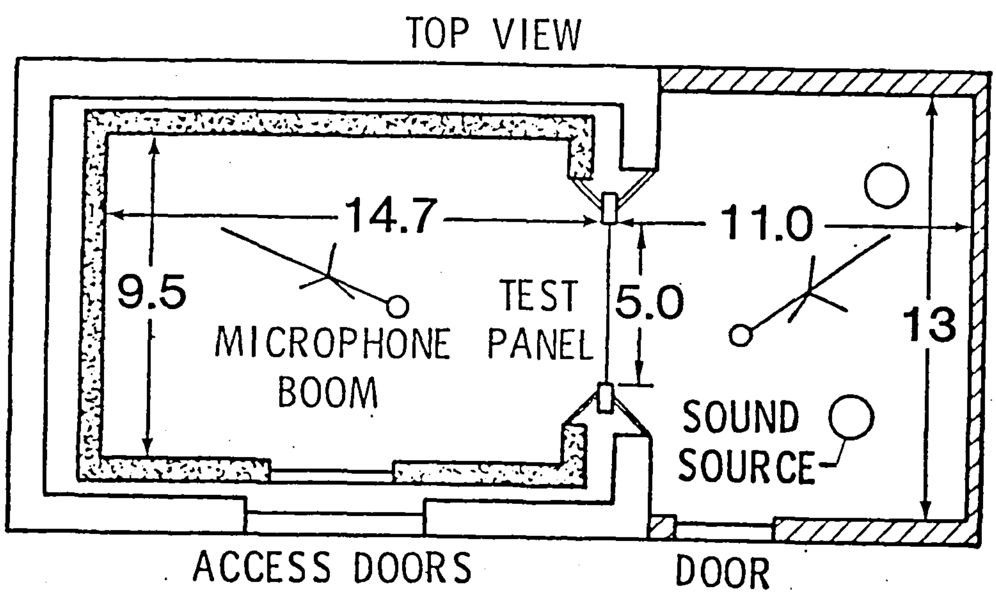

Figure 13.- Laboratory transmission loss test apparatus. Dimensions in feet.

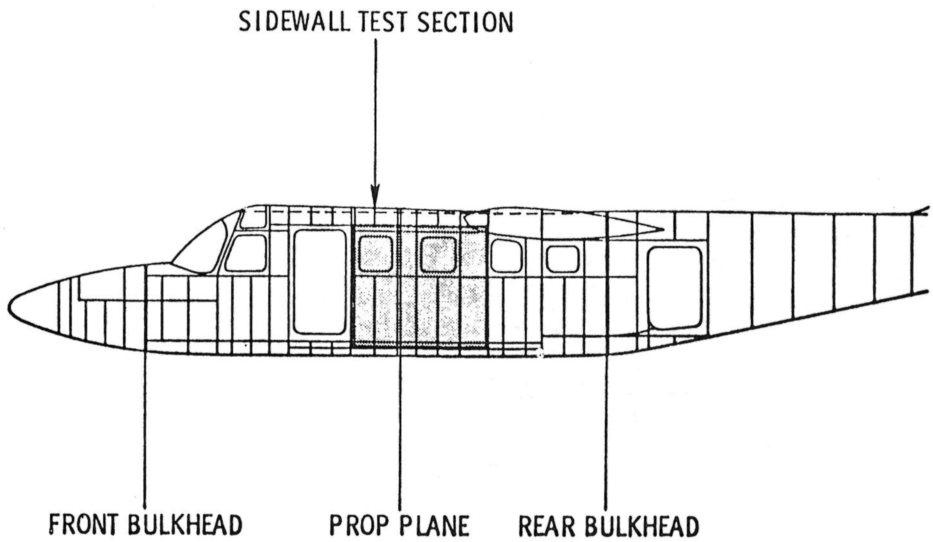

Figure 14.- Section of aircraft sidewall modeled for lab study.

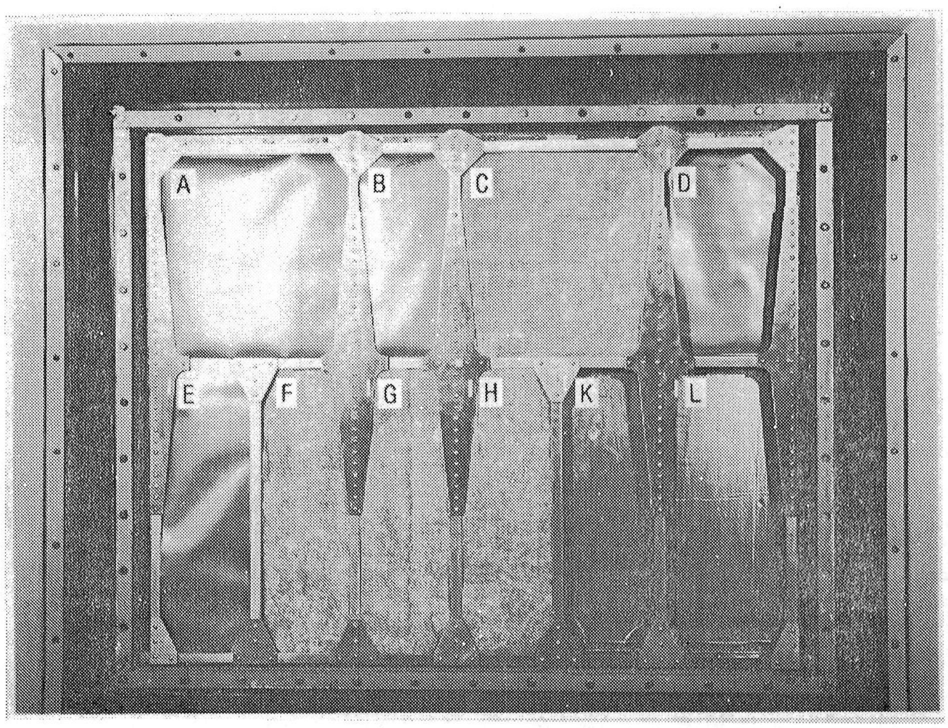

Figure 15.- Laboratory test panel in test position.

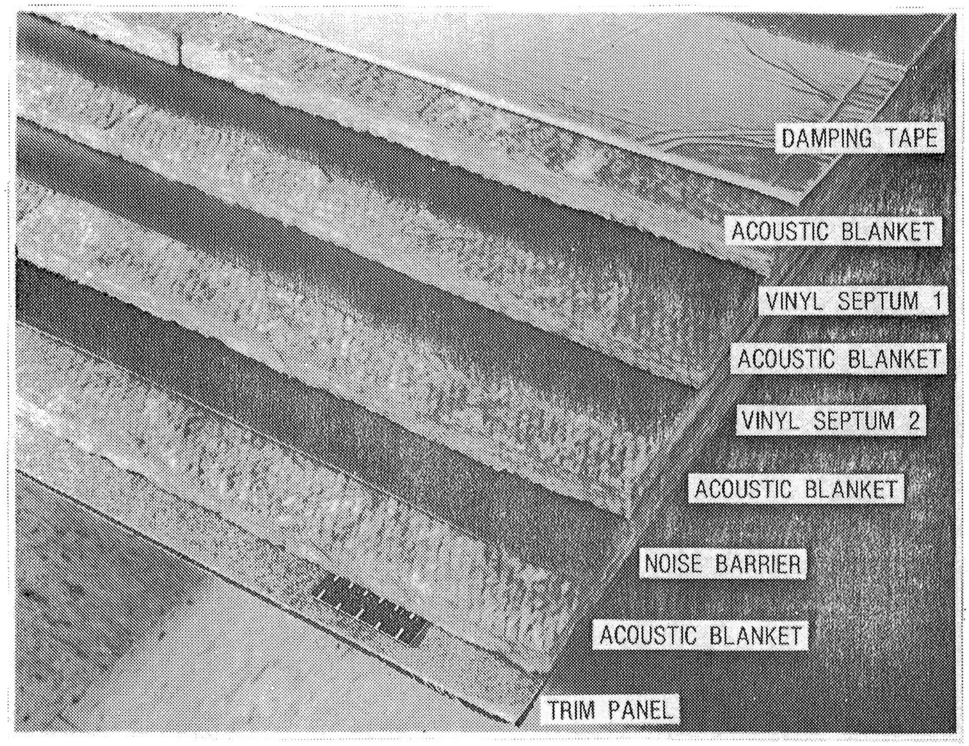

Figure 16.- Acoustic treatment elements used in lab study.

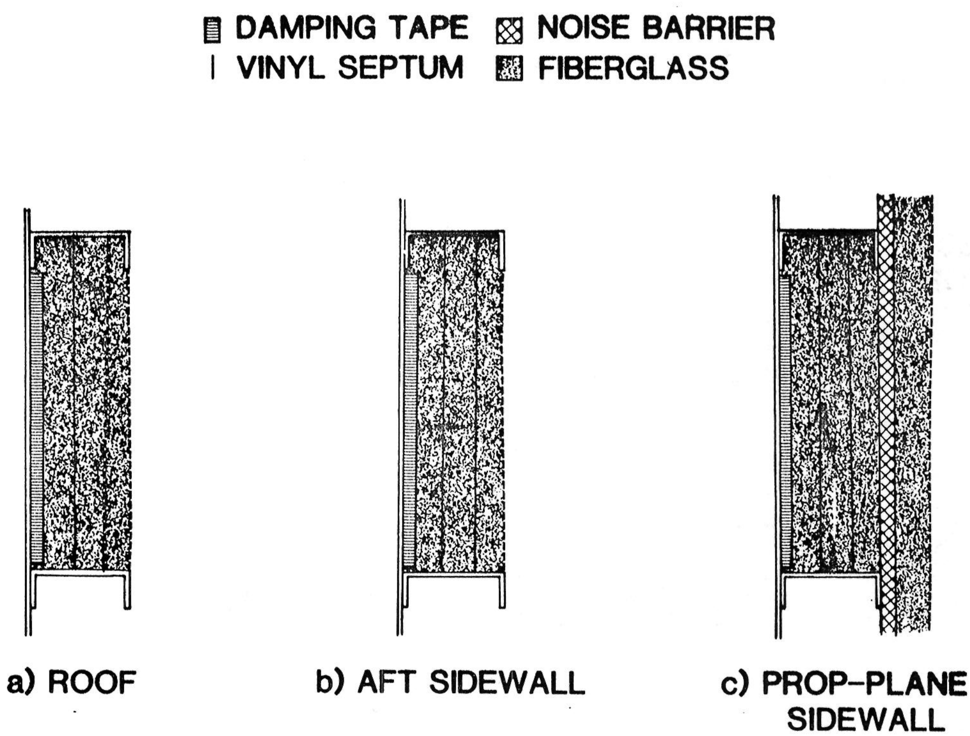

Figure 17.- Acoustic treatment configurations for lab study.

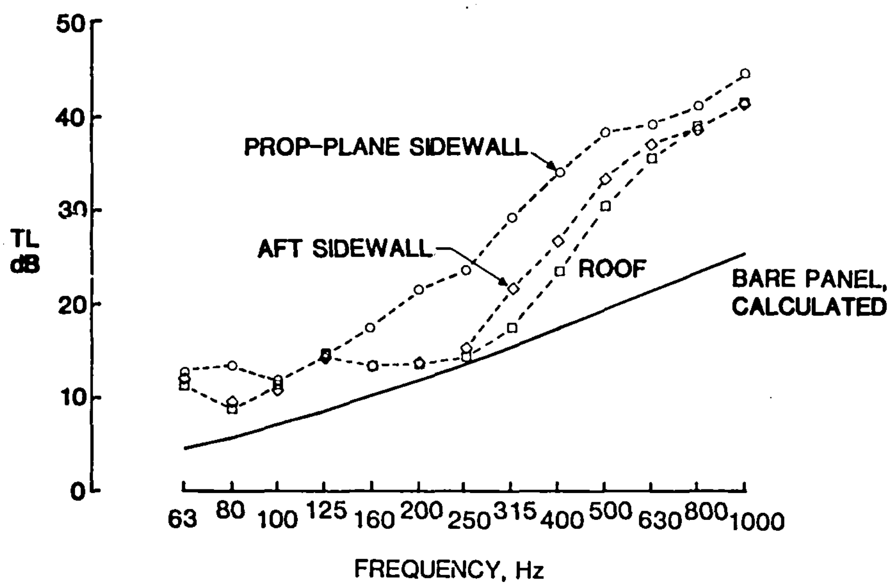

Figure 18.- Transmission loss of panel and acoustic treatment measured in the lab.

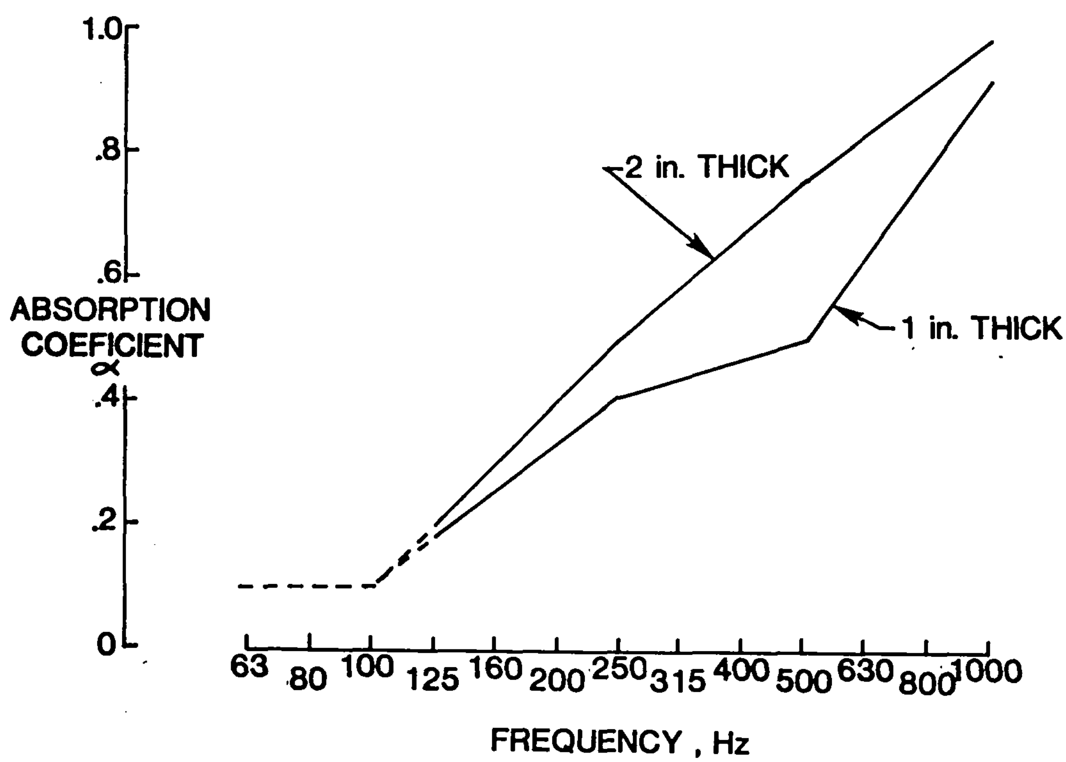

Figure 19.- Absorption coefficients of fiberglass used in calculating insertion loss. Data from reference 5.

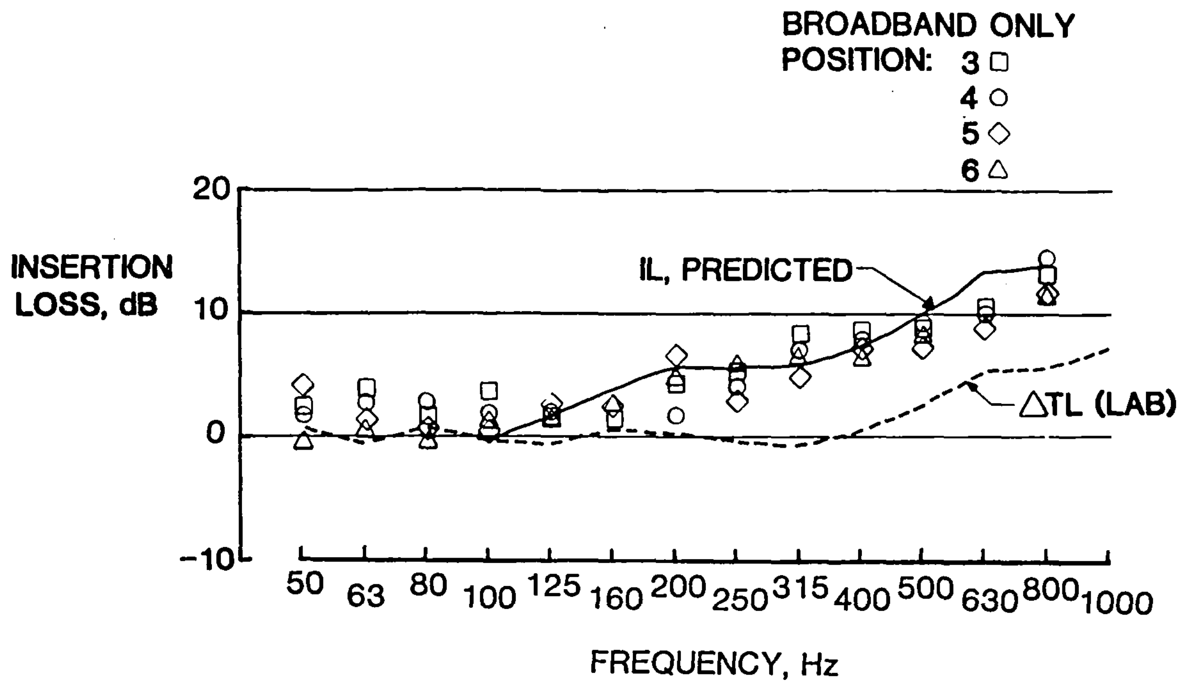

Figure 20.- Insertion loss of 2 in. of fiberglass relative to no treatment, comparison of predictions with flights data.

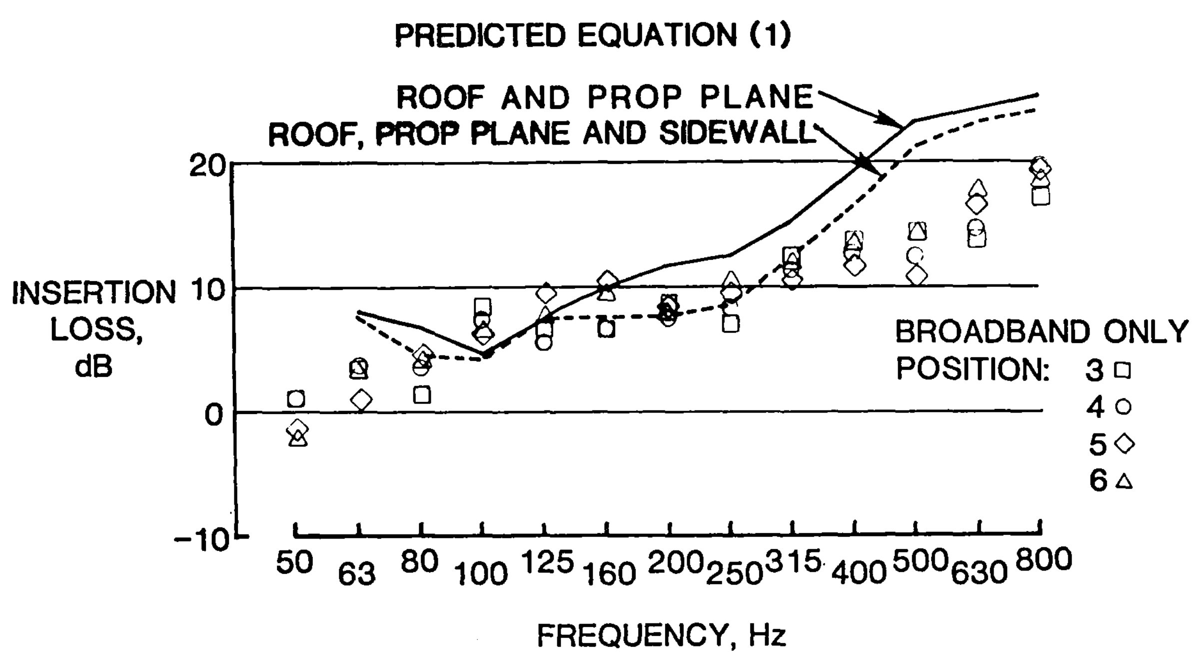

Figure 21.- Insertion loss of 695A treatment relative to no treatment, comparison of predictions with flight data.

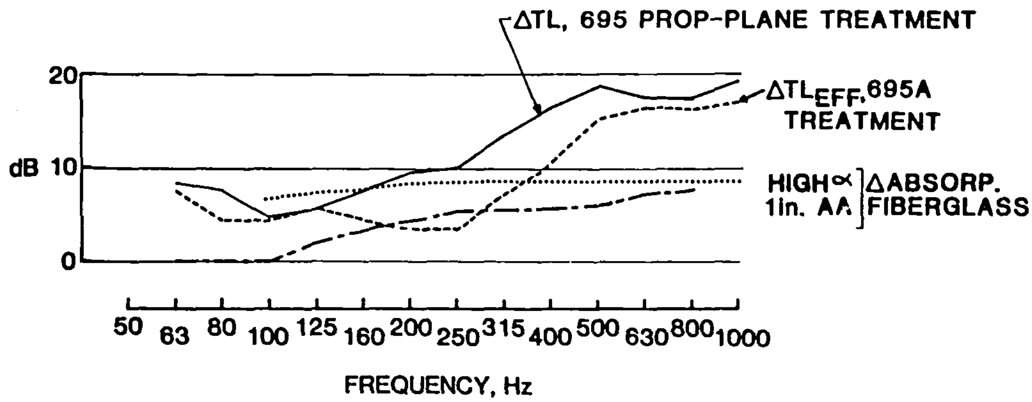

Figure 22.- Component contribution to insertion loss of acoustic treatment.

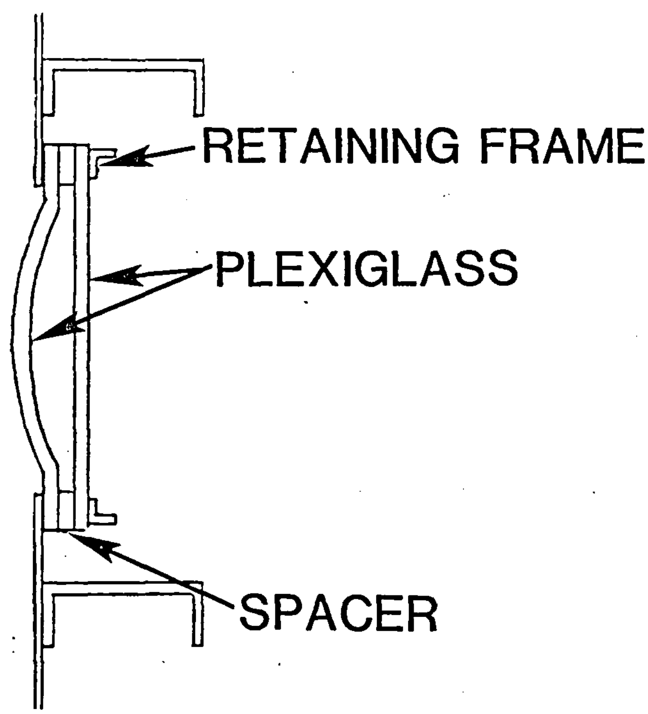

Figure 23.- Sketch of typical window section.

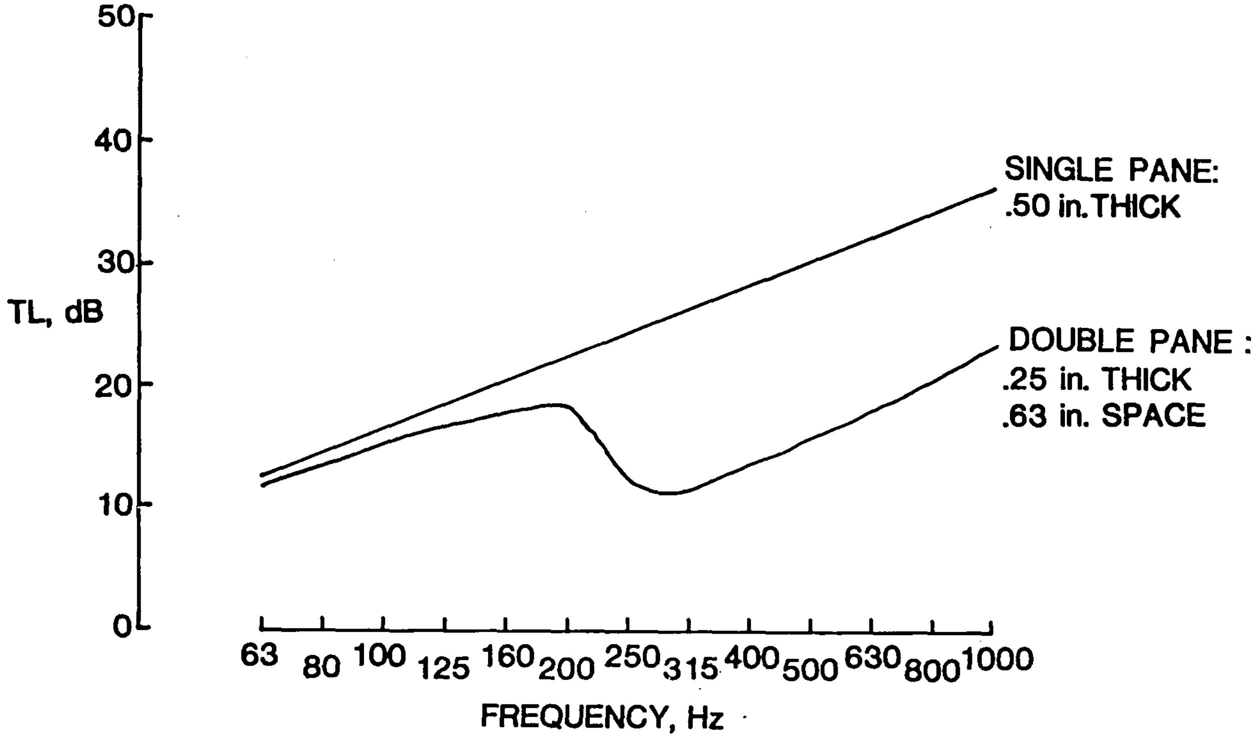

Figure 24.- Calculated transmission loss of approximate models of windows.

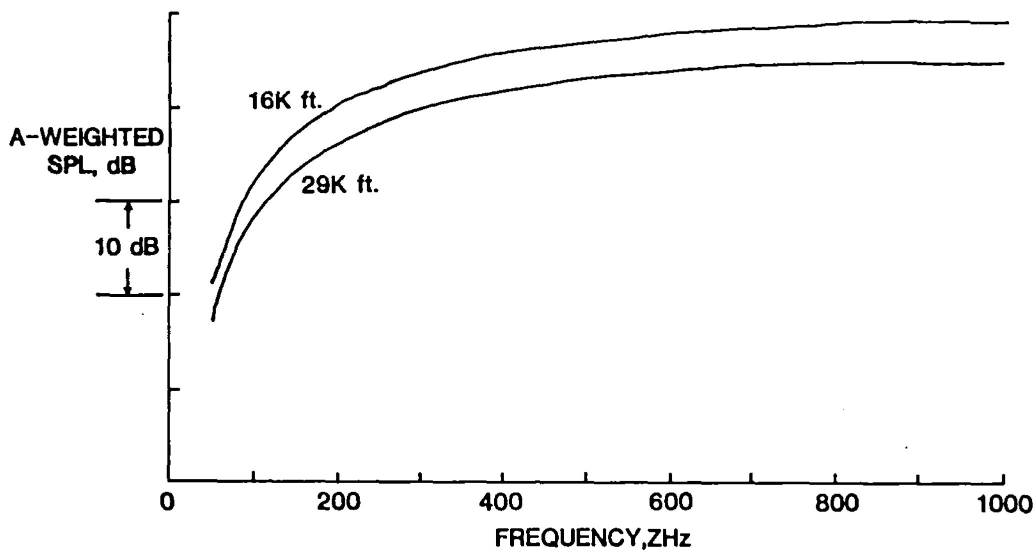

Figure 25.- Predicted spectrum of boundary layer fluctuating pressure on fuselage exterior.

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15. Supplementary Notes

*O'Neal -- Gulfstream Aerospace Corp., Bethany, OK
*Grosveld -- Bionetics Corp., Hampton, VA

16. Abstract

This paper describes a flight and laboratory study of sidewall acoustic treatment for cabin noise control. In flight, cabin noise levels were measured at six locations with three treatment configurations. Noise levels from narrow-band analysis are reduced to one-third octave format and used to calculate insertion loss, IL, defined as the reduction of interior noise associated with the addition of a treatment. Laboratory tests used a specially constructed structural panel modeled after the propeller plane section of the aircraft sidewall, and acoustic treatments representing those used in flight. Lab measured transmission loss and absorption values were combined using classical acoustic procedures to obtain a prediction of IL. Comparison with IL values measured in flight for the boundary layer component of the noise indicated general agreement.

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